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RESEARCH MEMORANDUM

SURVEY OF TWO-DIMENSIONAL DATA ON PITCHING-MOMENT CHANGES NEAR MAXIMUM LIFT CAUSED BY DEFLECTION OF HIGH-LIFT DEVICES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The large pitching-moment increments associated with deflection of certain types of trailing-edge high-lift devices have made it difficult or impossible to obtain trim during landing and take-off. As an aid in the selection of high-lift devices, therefore, a survey has been made of two-dimensional data on trim changes near maximum lift resulting from deflection of various types of leading-edge and trailing-edge high-lift devices. Increments of pitching-moment coefficient near maximum lift caused by deflection of trailing-edge high-lift devices when plotted against increments of maximum lift coefficient have been found to fall within a fairly narrow band, regardless of such variables as flap size or airfoil section. Trailing-edge devices which provide an increase in airfoil area produce much larger pitching-moment increments than devices which merely increase the airfoil camber. The addition of leading-edge high-lift devices, and particularly those leading-edge devices which extend to cause an increase in area, cause large reductions in the pitching-moment increments caused by trailing-edge-flap deflection. The use of extensible leading-edge devices with nonextensible trailing-edge devices seems to offer the best combination of high lift and low pitching-moment increments.

INTRODUCTION

The large pitching-moment increments associated with deflection of certain types of trailing-edge high-lift devices have made it difficult or impossible to obtain trim during landing and take-off. Although other factors such as ground effect influence trim, a comparison of the pitching-moment increments that result from deflection of various high-lift devices is useful to obtain the optimum flap type.

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A survey has been made of two-dimensional data on pitching-moment changes resulting from deflection of high-lift devices. Data are presented for various types of both leading-edge and trailing-edge devices which are in general use. A compilation is presented in reference 1 of data on airfoils equipped with various types of trailing-edge high-lift devices. The pitching-moment data considered in reference 1, however, were those near zero angle of attack. Due to the fact that pitching-moment curves for airfoils with high-lift devices are not generally linear, the pitching moments near zero lift may not be a good indication of the magnitude of pitching moments at high lift coefficients. The present analysis is therefore concerned only with pitching moments in the region of maximum lift.

SYMBOLS

c_l'	near-maximum section lift coefficient
$c_{m_{ac}}$	section pitching-moment coefficient about aerodynamic center of flapped airfoil for near-maximum lift coefficient
α_o'	angle of attack for near-maximum section lift coefficient, degrees
δ_f	angle of deflection of trailing-edge flap, degrees; positive when trailing edge is down
$\Delta c_l'$	increment in near-maximum section lift coefficient caused by deflection of high-lift devices
Δc_m	increment in section pitching-moment coefficient at near-maximum section lift coefficient caused by deflection of high-lift devices measured about aerodynamic center of plain airfoil
x_{ac}	chordwise position of aerodynamic center, percent chord; positive when aerodynamic center is to rear of leading edge
y_{ac}	position of aerodynamic center normal to chord line, percent chord; positive locations are below chord line

DISCUSSION

Sketches of the various types of high-lift devices treated in this paper are shown in figure 1. In figure 2, increments of pitching-moment coefficient about the plain-airfoil aerodynamic center have been plotted against increments of lift coefficient caused by deflection of various types of high-lift devices. The high-lift devices were at the position and deflection for the highest maximum lift coefficient. The data shown in this figure are for a lift coefficient near maximum lift but before any large change in pitching moment has resulted from the stall. In all cases this lift coefficient is greater than 90 percent of the maximum lift coefficient. Curves have been drawn in this figure to show the general trends of the data presented but are not intended to indicate a precise variation in these variables. In order to provide more detailed information on these configurations, all the data presented in figure 2 are listed in table I along with the sizes of high-lift devices used and references to the papers in which the data were originally presented. It must be realized that the pitching-moment data shown in figure 2 cannot be applied directly to finite-span wings but that they are shown herein merely as an indication of the relative merits of the various types of high-lift devices as far as their effect on section lift and pitching-moment changes is concerned. The effect of using different types of devices on different portions of the wing span in particular cannot be shown by these data but may be inferred since the characteristics of the complete wing are derived from a summation of the characteristics of the various sections along the span.

As shown by the data in figure 2, the pitching-moment increments caused by trailing-edge high-lift devices which do not increase the wing area fall within a fairly narrow, well-defined band regardless of such variables as flap size or airfoil section. (Data for those single slotted flaps with short slot-lip extensions are included in this group since they produce only small increases in area.) These data differ from the data shown in reference 1 for conditions near zero angle of attack. The data in reference 1 show that, at the low angles of attack, the pitching-moment data agree fairly well with thin-airfoil theory and that large moment changes occur as the flap-chord ratio is varied. The data shown in figure 2 for near-maximum lift indicate higher negative pitching-moment increments in all cases than the data at lower angles of attack.

The data for trailing-edge devices that increase area are also shown to fall within a fairly well-defined band although devices of this type cause much larger increases in pitching moment for a given increase in lift coefficient than the devices which do not increase area. This result could readily be anticipated since the increase in area resulting from extension of these devices is far behind the center of moments. Trailing-edge devices of this type can produce larger increases in maximum lift than the devices which do not increase area but do so only at the expense of much greater pitching moments.

Leading-edge devices increase maximum lift coefficients principally by delaying separation of the flow and therefore cause little change in pitching moments. Extensible leading-edge devices, because of the fact that the location of the high leading-edge load is moved forward, can actually decrease the negative pitching moments while increasing maximum lifts. As shown in figure 2, however, the increases in maximum lift produced by leading-edge devices alone are relatively small. Leading-edge high-lift devices also cause the maximum lift to occur at higher angles of attack, which restricts their use in some applications.

When leading-edge devices are used in conjunction with trailing-edge devices the advantages of both the trailing-edge increase in camber and the leading-edge delay in separation are obtained. The pitching-moment increments resulting from such combinations with no increase in area are of very nearly the same magnitude as those for the trailing-edge devices alone. Data are shown for only one combination for which the trailing-edge device extends but the leading edge does not extend. The pitching-moment increment for this configuration shows a definite decrease resulting from the use of the leading-edge devices.

When a leading-edge device is extended, decreases in negative pitching moment result because a large portion of the load is carried forward of the normal airfoil leading edge. Extensible leading-edge devices in combination with either extensible or nonextensible trailing-edge devices are readily seen to provide the largest increments in maximum lift of any of the devices considered. If extensible leading-edge devices are added to airfoils with nonextensible trailing-edge devices, increases in lift increments occur with reductions in pitching-moment increments. (Compare configurations 5 with 8 and 13 with 15, table I.) If extensible leading-edge devices are added to airfoils with extensible trailing-edge devices, however, increases in maximum lifts alone occur with little reduction in pitching-moment increments. (Compare configurations 33 with 35 and 36, table I.) For this reason, extensible leading-edge devices combined with nonextensible trailing-edge devices seem to offer the best combination of high lift and moderate pitching-moment increments.

As an aid in the application of section data on high-lift devices to the computation of finite-span wing characteristics, detailed information on the near-maximum lift coefficients, angles of attack at which they occur, aerodynamic-center positions, and the pitching-moment coefficients about the aerodynamic center for a number of high-lift devices at various deflections are shown in figure 3. The variations of pitching-moment coefficient with lift coefficient for airfoil sections with high-lift devices are not generally linear so that an exact aerodynamic-center position covering conditions throughout the entire lift range does not exist. The aerodynamic-center positions shown in figure 3 were computed by the method of reference 28 for conditions that exist near maximum lift but apply through a range of lift coefficient of about 0.8 below c_l'.

CONCLUDING REMARKS

A compilation has been made of a large amount of two-dimensional data on trim changes near maximum lift resulting from deflection of various types of high-lift devices. Increments of pitching-moment coefficient near maximum lift caused by deflection of trailing-edge high-lift devices when plotted against increments in maximum lift coefficient have been found to fall within a fairly narrow band, regardless of such variables as flap size or airfoil section. Trailing-edge devices which provide an increase in airfoil area produce much higher pitching-moment increments than devices which merely increase the airfoil camber. The addition of leading-edge high-lift devices, and particularly those leading-edge devices which extend to cause an increase in area, cause large reductions in the pitching-moment increments caused by trailing-edge-flap deflection. The use of extensible leading-edge devices with nonextensible trailing-edge devices seems to offer the best combination of high lift and low pitching-moment increments.

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TABLE I

SUMMARY OF LIFT AND PITCHING-MOMENT INCREMENTS

Configuration	Airfoil	Trailing-edge devices		Leading-edge devices		Δc_l	Δc_m	Reference
		Type	Chord	Type	Chord			
1	NACA 23012	(a)	0.20	---	-----	0.83	-0.180	Ref. 2, fig. 9
2	NACA 23012	(a)	.20	---	-----	.80	-.182	Ref. 3, figs. 2, 3
3	NACA 65-210	(a)	.50	---	-----	.37	-.070	Ref. 4, figs. 1 to 4
4	NACA 23012	(b)	.10	---	-----	.73	-.200	Ref. 5, fig. 8(a)
5	NACA 23012	(b)	.20	---	-----	1.01	-.230	Ref. 5, fig. 8(b)
6	NACA 23012	(b)	.30	---	-----	1.02	-.255	Ref. 5, fig. 8(c)
7	NACA 23012	(b)	.40	---	-----	1.06	-.245	Ref. 5, fig. 8(d)
8	NACA 23012	(b)	.20	(b)	0.155	1.22	-.110	Ref. 6, fig. 8(a)
9	NACA 23012	(d)	.15	---	-----	1.09	-.370	Ref. 7, fig. 21
10	NACA 23012	(d)	.25	---	-----	1.66	-.609	Ref. 7, fig. 25
11	NACA 23012	(d)	.30	---	-----	1.71	-.709	Ref. 8, fig. 3
12	NACA 23012	(d)	.30	---	-----	1.34	-.509	Ref. 8, fig. 8
13	NACA 23012	(c)	.256	---	-----	1.15	-.296	Ref. 2, fig. 15
14	NACA 23012	(d)	.40	---	-----	1.23	-.365	Ref. 9, fig. 9
15	NACA 23012	(c)	.256	(b)	.155	1.49	-.215	Ref. 6, fig. 7
16	NACA 23012	(e)	.30	---	-----	1.63	-.635	Ref. 10, fig. 15(a)
17	NACA 23021	(b)	.10	---	-----	.85	-.252	Ref. 5, fig. 9(a)
18	NACA 23021	(b)	.20	---	-----	1.27	-.323	Ref. 5, fig. 9(b)
19	NACA 23021	(b)	.30	---	-----	1.42	-.348	Ref. 5, fig. 9(c)
20	NACA 23021	(b)	.40	---	-----	1.45	-.398	Ref. 5, fig. 9(d)
21	NACA 23021	(c)	.256	---	-----	1.24	-.348	Ref. 11, fig. 14
22	NACA 23021	(d)	.40	---	-----	1.25	-.368	Ref. 12, fig. 9
23	NACA 23021	(e)	.32	---	-----	1.75	-.727	Ref. 13, fig. 14(a)
24	NACA 66,2-216	(c)	.25	---	-----	1.30	-.375	Ref. 14, fig. 7
25	NACA 63,4-420	(c)	.25	---	-----	1.54	-.378	Ref. 15, fig. 6
26	NACA 23012	(b)	.20	(a)	.180	1.03	-.230	Ref. 16, fig. 5
27	NACA 23012	(b)	.20	(a)	.300	1.27	-.255	Ref. 17, fig. 5
28	NACA 23012	(c)	.256	(a)	.180	1.38	-.365	Ref. 16, fig. 6
29	NACA 23012	(c)	.256	(a)	.300	1.60	-.390	Ref. 17, fig. 6
30	NACA 23012	---	-----	(b)	.155	.48	.060	Ref. 6, fig. 8(a)
31	NACA 23012	---	-----	(a)	.180	.42	-.040	Ref. 16, fig. 5
32	NACA 23012	---	-----	(a)	.300	.66	-.080	Ref. 17, fig. 5
33	Clark Y	(d)	.40	---	-----	1.90	-.822	Ref. 18, fig. 9
34	Clark Y	---	-----	(b)	.130	.82	.001	Ref. 18, fig. 9
35	Clark Y	(d)	.40	(b)	.130	2.11	-.778	Ref. 18, fig. 9
36	Clark Y	(d)	.40	(b)	.130	2.36	-.769	Ref. 18, fig. 9
37	NACA 0009	---	-----	(c)	.054	.32	-.040	Ref. 19, fig. 2
38	NACA 0009	(d)	.25	(c)	.054	1.49	-.440	Ref. 19, fig. 2
39	NACA 0009	---	-----	(c)	.144	.58	-.020	Ref. 20, fig. 3
40	Clark Y	---	-----	(a)	.175	.53	-.060	Ref. 21, fig. 6(a)
41	Clark Y	---	-----	(a)	.300	.81	-.117	Ref. 21, fig. 6(b)
42	Clark Y	(b)	.20	(a)	.175	1.03	-.195	Ref. 21, fig. 6(a)
43	Clark Y	(b)	.20	(a)	.300	1.27	-.295	Ref. 21, fig. 6(b)
44	NACA 23018	---	-----	(b)	.222	.70	.020	Ref. 22, fig. 8
45	NACA 23012	---	-----	(b)	.166	.85	.015	Ref. 22, fig. 13
46	NACA 23018	(c)	.40	(b)	.222	2.08	-.270	Ref. 22, fig. 7
47	NACA 23018	(c)	.40	(b)	.222	2.19	-.355	Ref. 22, fig. 10
48	NACA 23012	(c)	.40	(b)	.166	2.22	-.370	Ref. 22, fig. 13
49	NACA 64_1-012	---	-----	(d)	.10	.13	.050	Ref. 23, fig. 8
50	NACA 64_1-012	---	-----	(d)	.10	.41	.065	Ref. 23, fig. 8
51	NACA 64_1-012	(b)	.20	(d)	.10	1.18	-.195	Ref. 23, fig. 8
52	NACA 64_1-012	(b)	.20	(d)	.10	1.56	-.075	Ref. 23, fig. 8
53	NACA 64-009	---	-----	(d)	.10	.74	.075	Ref. 24, fig. 9
54	NACA 64-009	(b)	.20	(d)	.10	1.55	-.090	Ref. 24, fig. 9
55	6-percent circular arc	---	-----	(c)	.15	.41	-.086	Ref. 25, fig. 6(a)
56	6-percent circular arc	(a)	.20	(c)	.15	1.20	-.291	Ref. 25, fig. 11(a)
57	10-percent circular arc	---	-----	(c)	.15	.41	-.091	Ref. 25, fig. 6(b)
58	10-percent circular arc	(a)	.20	(c)	.15	1.27	-.338	Ref. 25, fig. 11(b)
59	6-percent circular arc	(a)	.20	(b)	.15	1.25	-.231	Ref. 26, fig. 8
60	NACA 65A006	---	-----	(c)	.15	.39	-.050	Ref. 27, fig. 6
61	NACA 65A006	(a)	.20	(c)	.15	1.09	-.244	Ref. 27, fig. 8

Types of trailing-edge device

(a) Plain flap
(b) Split flap
(c) Slotted flap
(d) Extensible slotted flap
(e) Double slotted flap

Types of leading-edge device

(a) Slot
(b) Extensible slat
(c) Drooped flap
(d) Extensible flap

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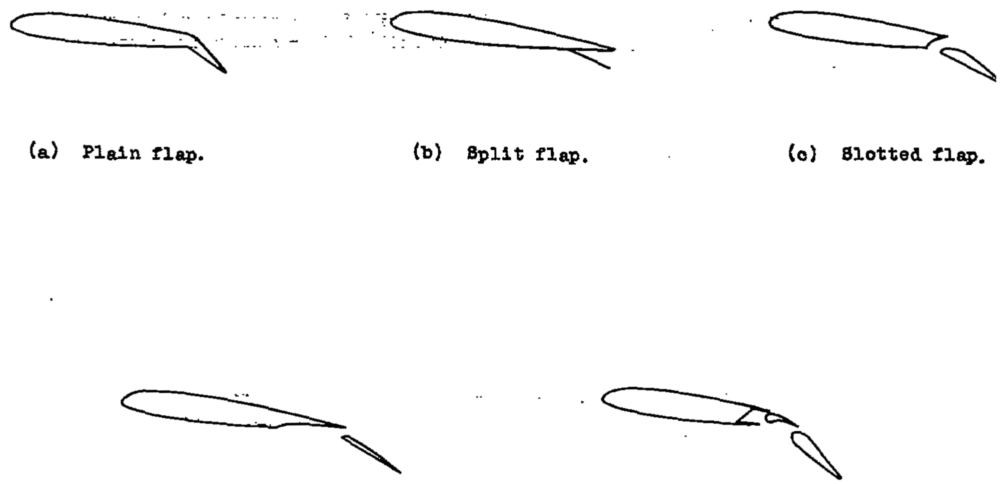
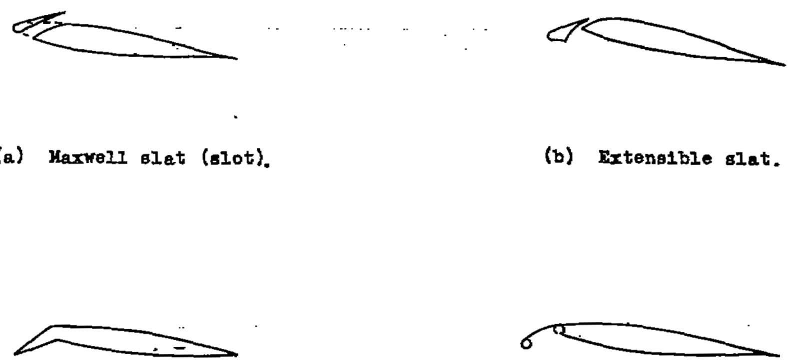


(a) Plain flap. (b) Split flap. (c) Slotted flap.

(d) Extensible slotted flap. (e) Double slotted flap.

Trailing-Edge Devices



(a) Maxwell slat (slot). (b) Extensible slat.

(c) Drooped flap. (d) Extensible flap.

Leading-Edge Devices

Figure 1.- General arrangement of various types of flaps and slats.

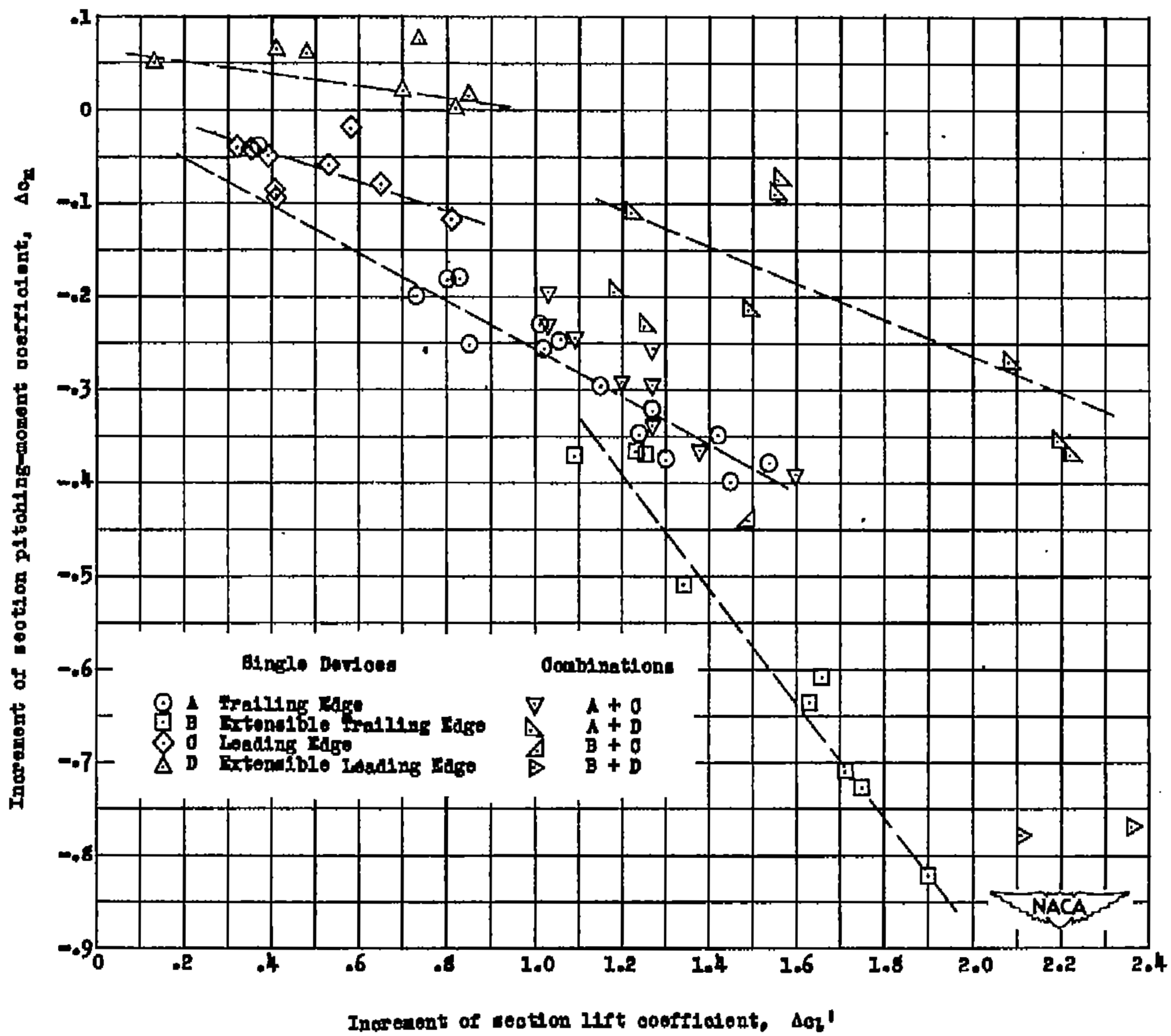
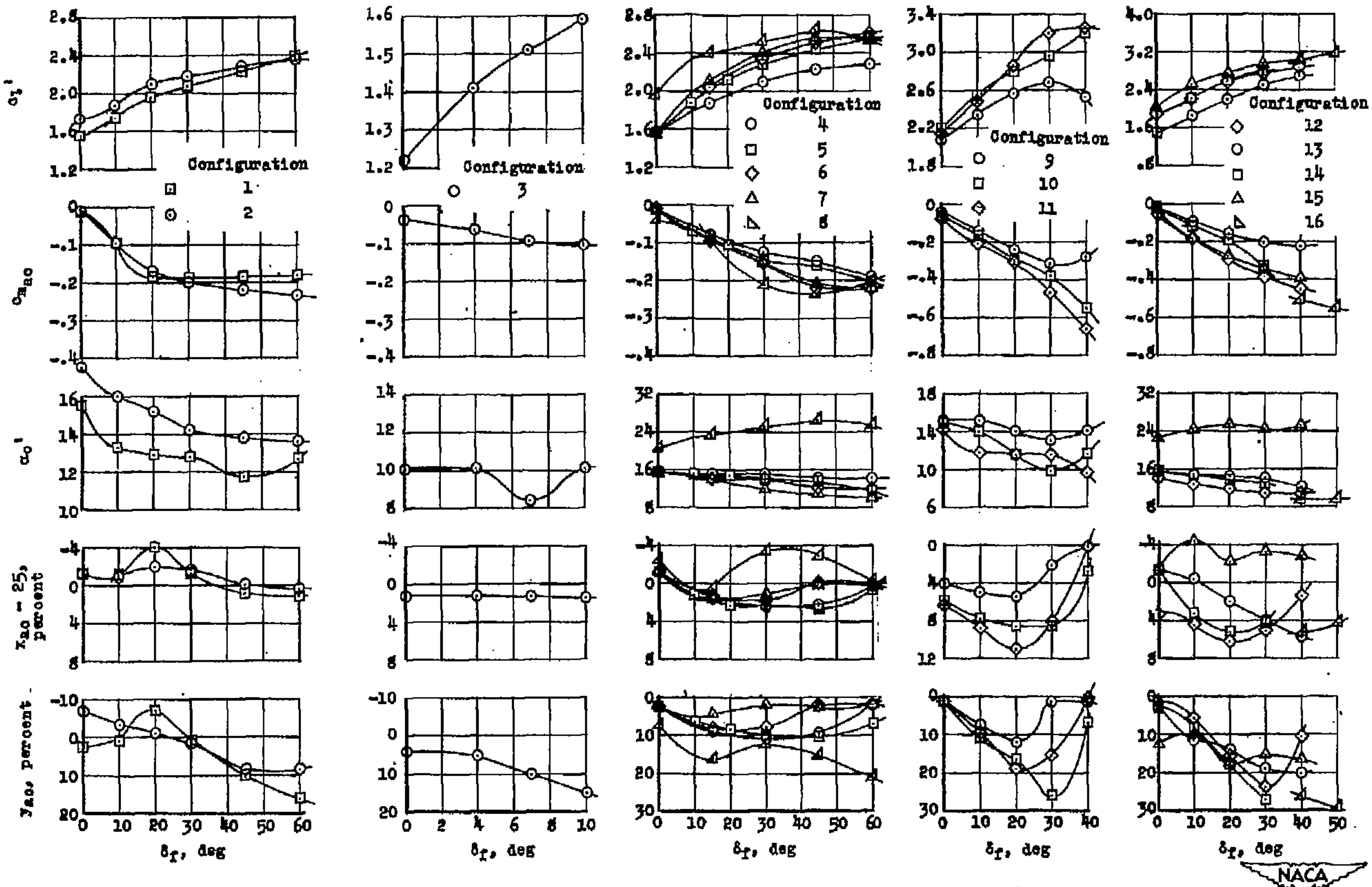


Figure 2.- Increments of section pitching moment caused by deflection of various types of high-lift devices.



(a) NACA 23012 airfoil, plain flaps.

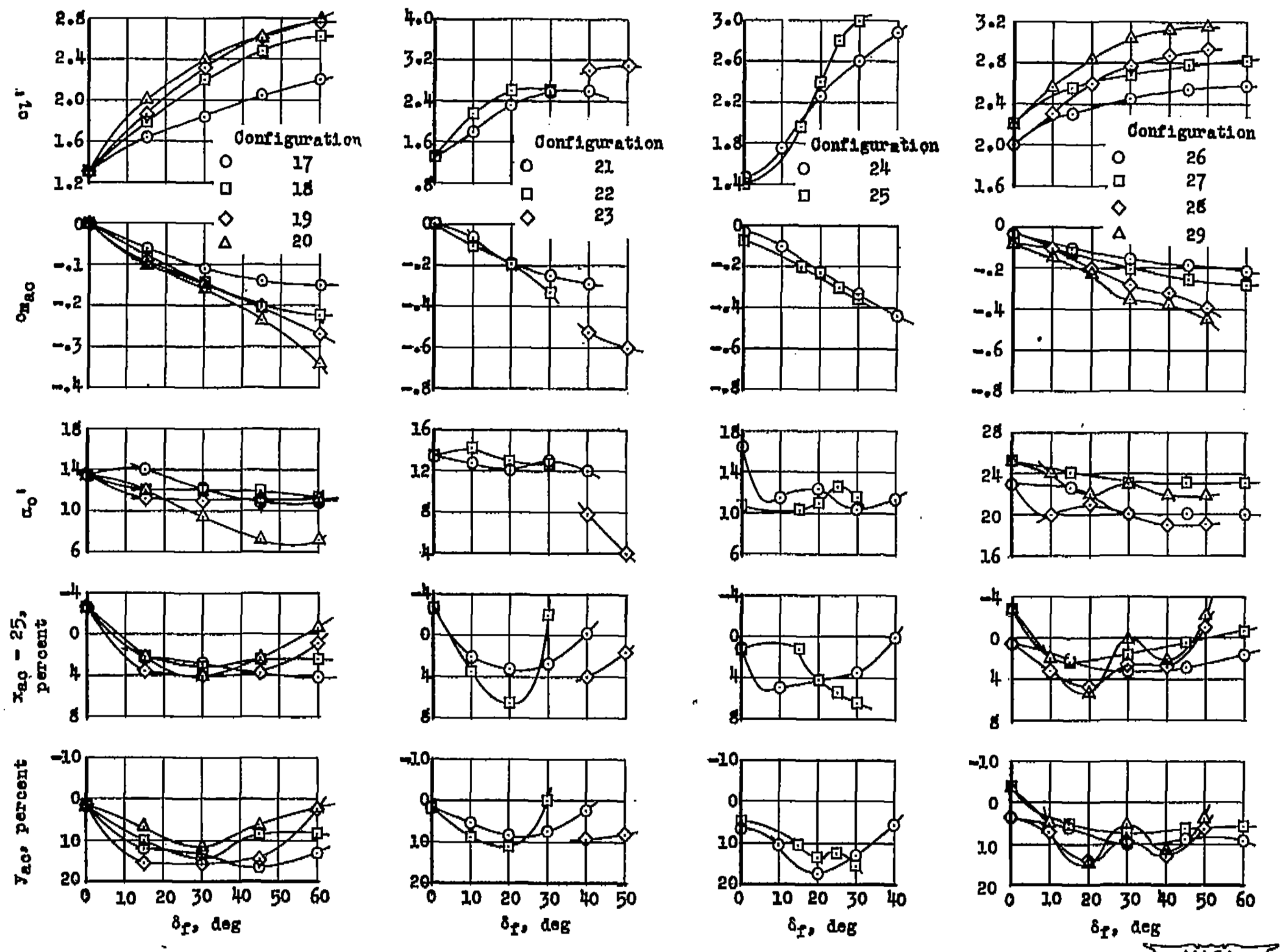
(b) NACA 65,210 airfoil, plain flaps.

(c) NACA 23012 airfoil, split flaps, split flap and Handley-Page slat.

(d) NACA 23012 airfoil, Fowler flaps.

(e) NACA 23012 airfoil, single and double slotted flaps, single slotted flap and Handley-Page slat.

Figure 3.- Aerodynamic characteristics near-maximum section lift coefficient of several NACA airfoils with various high-lift devices.



(f) NACA 23021 airfoil, split flaps.

(g) NACA 23021 airfoil, single and double slotted flaps.

(h) NACA 6-series airfoils, single slotted flaps.

(i) NACA 23012 airfoil, split or single slotted flaps and Maxwell slat.

Figure 3.- Concluded.